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(56) Documents Cited
EP 0772249 A2 JP 008032112 A US 5652438 A
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(71) Applicant(s)
Hewlett-Packard Company
(Incorporated in USA - Delaware)
3000 Hanover Street, Palo Alto, California 94303, United States of America

(72) Inventor(s)
Daniel A Steigerwald

(74) Agent and/or Address for Service
Williams, Powell & Associates
4 St Paul's Churchyard, LONDON, EC4M 9AY, United Kingdom

(54) Abstract Title
Light emitting device

(57) In a QW LED employing the Al In Ga N material system an intentional impurity is introduced in the quantum well active region to increase the efficiency of the LED (10) and to increase the emission wavelength beyond that of an undoped QW LED. In addition, an intentional impurity similar to that found in an adjacent layer can reduce the uncontrollable or undesirable effects of impurity diffusion.

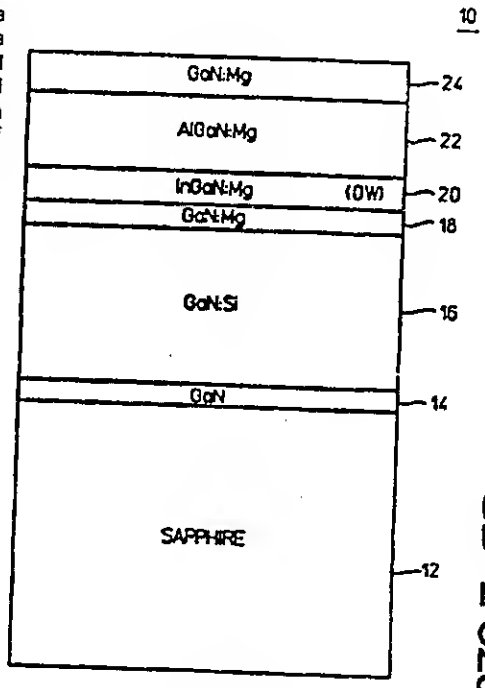

Figure 1

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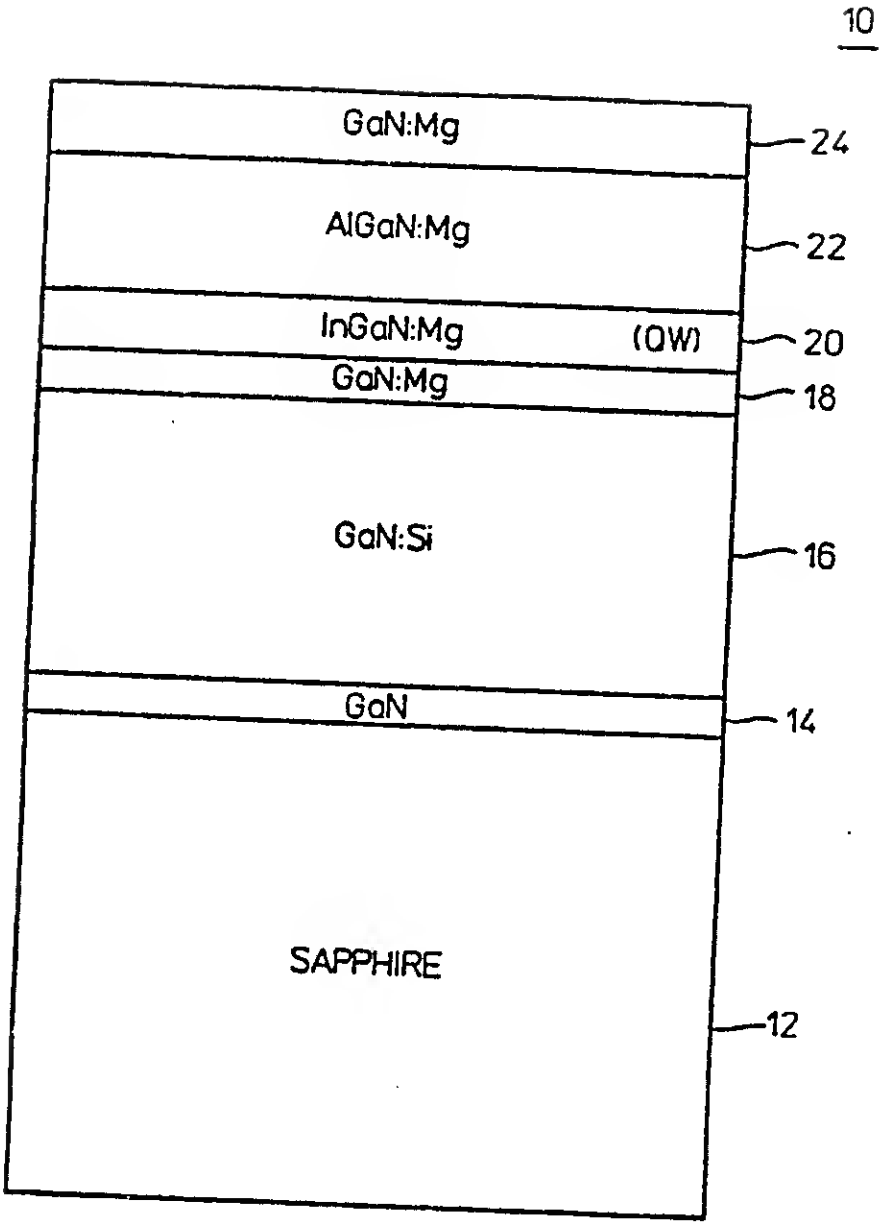
10
GaN:Mg
24
AlGaN:Mg
22
InGaN:Mg
(QW)
20
GaN:Mg
18
GaN:Si
16
GaN
14
SAPPHIRE
12

Figure 1

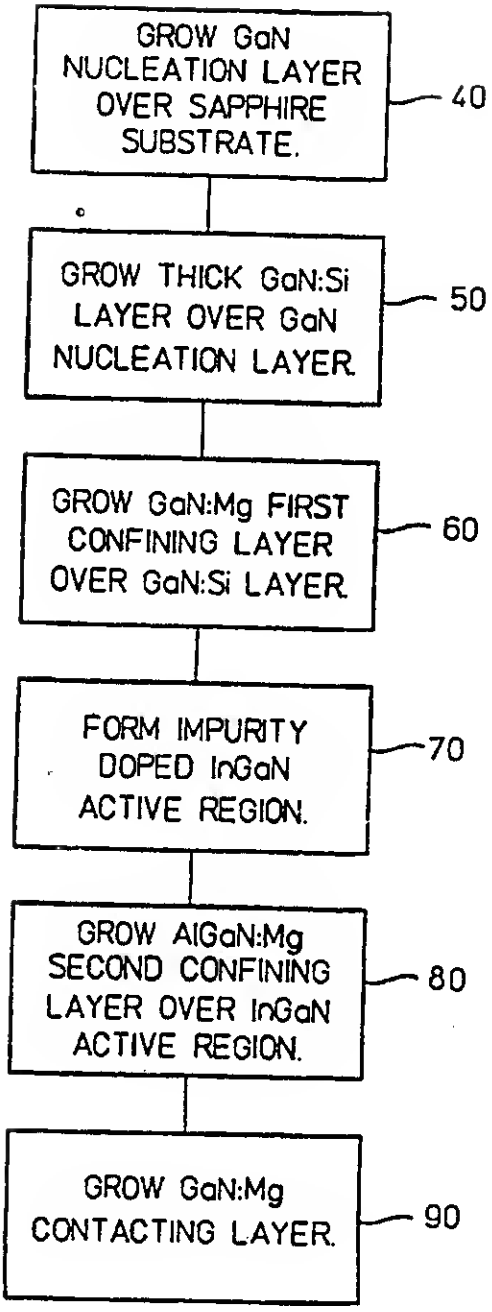
GROW GaN NUCLEATION LAYER OVER SAPPHIRE SUBSTRATE.
40
GROW THICK GaN:Si LAYER OVER GaN NUCLEATION LAYER.
50
GROW GaN:Mg FIRST CONFINING LAYER OVER GaN:Si LAYER.
60
FORM IMPURITY DOPED InGaN ACTIVE REGION.
70
GROW AlGaN:Mg SECOND CONFINING LAYER OVER InGaN ACTIVE REGION.
80
GROW GaN:Mg CONTACTING LAYER.
90

Figure 2

LIGHT EMITTING DEVICE

The invention relates to a semi conductor light-emitting device.

Highly efficient visible light-emitting devices (LEDs) have been produced in the red, orange, and yellow spectral regions by employing the $Al_xGa_{1-x}As$ and $In_y(Al_xGa_{1-x})P$ material systems and Double Heterostructure device structures which employ a "bulk" active region in the thickness range of 0.1 to 5.0 μm in thickness. These highly efficient LEDs use a direct band-to-band transition to produce the light of an appropriate wavelength.

Recently highly efficient blue LEDs, commercialized by Nichia and Toyoda Gosei, employ the AlInGaN materials system in conjunction with a "bulk" active region, 0.05 to 0.10 μm in thickness, which is "co-doped" with both silicon and zinc. Co-doping has two positive effects. First, the extremely high defect density associated with epitaxial GaN leads to inefficient band-to-band transitions in undoped material, whereas the Zn-Si pairs provide an extremely efficient mechanism for light emission. Second, the selection of Zn-Si pairs shifts the wavelength substantially, from 380 nm to 450 nm for the emission from the band-to-band and Zn-Si impurity centers, respectively. The shift in wavelength alone increases the detection efficiency of the human eye by almost a factor of 1000. Such an LED structure is acceptable for the blue spectral region, however, when attempts are made to shift the wavelength into the green spectral region by increasing the mole fraction of indium in the active

region (x in the formula $In_xGa_{1-x}N$), the result is an LED of poor color purity, with a "whitish" color. There is a great commercial need for highly efficient, spectrally pure green and blue-green LEDs.

Highly efficient blue and green LEDs have been commercialized which employ the same AlInGaN materials system in conjunction with an extremely thin quantum well (QW) active region, with a thickness of approximately 3 nm. These devices employ an undoped QW region and direct band-to-band transitions to achieve the high efficiency and purer colors. Special processes and techniques are used to eliminate dopant incorporation and diffusion.

The present invention seeks to provide an improved light emitting device.

According to an aspect of the present invention there is provided a light-emitting device comprising a substrate;

a GaN nucleation layer, positioned on the substrate;

a Si-doped GaN current spreading layer positioned over the GaN nucleation layer;

a first and second confining layers positioned over the Si-doped GaN current spreading layer wherein the first and second confining layers contain a first and second impurity, respectively; and

a thin quantum well active region with a quantum well impurity, interposing the first and second confining layers wherein the quantum well impurity is selected to increase the light emission properties of the light-emitting device.

In the preferred embodiment, an intentional impurity is introduced in a quantum well (QW) LED active region to increase the efficiency of the LED and to increase the emission wavelength beyond that of an undoped QW LED. In addition, an intentional impurity similar to that found in an adjacent layer can reduce the uncontrollable or undesirable effects of impurity diffusion.

Preferably, a thin GaN nucleation layer is grown on a sapphire substrate. A thick Si-doped GaN layer is grown over the thin GaN nucleation layer. A first confining layer consisting of GaN: Mg is grown over an n-type GaN layer. A thin $In_xGa_{1-x}N$ QW active region is grown over the first confining layer. The thin QW active region has been optionally doped. A second confining layer consisting of GaN-based compound is positioned over the thin QW active region. The first and second confining layers are doped, either alone or in combination.

An embodiment of the present invention us described below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 illustrates an embodiment of a light emitting device; and

Figure 2 illustrates a flowchart of a preferred method for producing the device shown in Figure 1.

Figure 1 illustrates a preferred embodiment of a light emitting device 10. A GaN nucleation layer 14 is positioned on a substrate 12, such as a sapphire substrate. A thick n-type GaN layer 16, doped with Si impurities, is formed over the GaN nucleation layer 14. A first confining layer 18 consisting of a GaN-based compound, doped with Mg impurities, is positioned over the thick Si-doped GaN layer 16. A thin $In_xGa_{1-x}N$ quantum well (QW) active region 20 is positioned over the first confining layer 18. The thin QW active region 20 has been intentionally doped with magnesium (Mg). A second confining layer 22 consisting of AlGaN that is optionally doped with Mg is positioned over the thin QW active region 20. The first and second confining layers are doped with Mg, either alone or in combination. A contacting layer 24 consisting of a GaN-based compound, doped with Mg is positioned over the second confining layer 22.

The intentional impurity introduced in a quantum well (QW) LED active region increases the efficiency of the LED and increases the emission wavelength beyond that of an undoped QW LED. In addition, adding a similar intentional impurity to one of the confining layers can reduce the uncontrollable or undesirable effects of impurity diffusion. Alternatively, the layers "confining" the QW active region may include $Al_xGa_{1-x}N$. If improving the internal efficiency of the QW active region is desired, these impurities may be donors or acceptors. If improving the injection efficiency of the QW active region is desired, the impurities are acceptors. Donors may be from Group VI such as oxygen, sulfur, selenium, or tellurium or Group IV such as silicon, germanium, or tin. Acceptors may be from Group IIA, e.g. magnesium, beryllium, or calcium, or Group IIB e.g. zinc or cadmium, or Group IV, e.g. carbon. In addition, rare earth elements from lanthanide group have been shown to be efficient emission centers in other materials and may be highly efficient in the AlInGaN material system.

The preferred embodiment influences the overall efficiency of a light emitting diode by four distinct methods. The overall efficiency of a visible LED may be defined as the product of several individual, independent efficiencies, as:

$$\eta_{external} = \eta_{internal} \times \eta_{injection} \times \eta_{extraction} \times \eta_{detector}$$

The internal efficiency, $\eta_{internal}$, is the fraction of injected minority carriers which emit photons. The injection efficiency, $\eta_{injection}$, is the fraction of the current that is transported into the active region. The extraction efficiency, $\eta_{extraction}$, is the fraction of photons which escape the crystal. For visible LEDs, the detector efficiency, $\eta_{detector}$, is the magnitude of the eye response per unit of radiant power.

The internal efficiency is increased by the impurity-related emission, which is more efficient than the near band-edge emission due to the high density of crystal defects.

The injection efficiency is increased due to the change in minority carrier injection from holes to electrons. This is important for two reasons; first the ratio of the electron concentration in the n-layer, to the hole concentration in the p-layer is significantly greater than 1, favoring electron injection. Second, the electrons in GaN-based material have a much lower effective mass, and a much higher mobility than the holes.

The extraction efficiency can be enhanced, as the impurity-related emission is not as strongly absorbed in the active region as near band-edge light.

The detector efficiency of blue and green LEDs are strongly affected by the emission wavelength, with an increae in wavelength increasing the response of the human eye. The impurity-related emissions in the prefered embodiment shift the emission wavelength longer, resulting in enhanced detection.

Figure 2 illustrates a process flow chart for the device shown in Figure 1. In step 40, the first thin GaN nucleation layer is formed directly on the sapphire substrate

at a low growth temperature such as 520 C. In step 50, the GaN:Si layer is formed directly on the nueleation layer at growth temperatures at approximately 1050C, while the thiekness may vary between 2 μm to 5 μm in thiekness. In step 60, the first confining layer is formed over the GaN:Si layer. In step 70, the Mg-doped InGaN QW active region is formed over the first confining layer at a growth temperature that ranges from 650C to 850C, while the thickness of the QW active region is typically 3 nm in thiekness. In step 80, the Mg-doped GaN layer is formed over the QW active region at a growth temperature that ranges from 650C to 1100C while the thickness may vary between 0.1 to 1.0 :m.

These layers may be grown using one of many available techniques such as organometallic vapor phase epitaxy (OMVPE), metal-organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), gas phase MBE (GPMBE), or hydride vapor phase epitaxy (HVPE).

The disclosures in United States patent application no. 08/815, 097, from which this applieation elaims priority, and in the abstract accompanying this applieation are ineorporated herein by reference.

CLAIMS

1. A light-emitting device comprising:

a substrate;

A GaN nucleation layer positioned on the substrate;

a Si-doped GaN current spreading layer positioned over the GaN nucleation layer;

first and second confining layers positioned over the Si-doped GaN current spreading layer, wherein the first and second confining layers contain a first and second impurity, respectively: and

a thin quantum well active region with a quantum well impurity, interposing the first and second confining layers, wherein the quantum well impurity is selected to increase the light emission properties of the light-emitting device.

2. A light-emitting device according to claim 1, wherein the first impurity is selected to increase the light emission property of the light-emitting device by improving the injection efficiency.

3. A light-emitting device according to claim 1, wherein the quantum well and first impurities are the same element, wherein the element is selected to effect impurity diffusion in the active region.

4. A light-emitting device according to claim 1, 2 or 3, wherein the quantum well impurity is a donor element.

5. A light-emitting device according to claim 1, 2, or 3, wherein the quantum well impurity is an acceptor element.

6. A light emitting device according to claim 5, wherein the acceptor element is selected from a group comprising Group IIA and Group IIB elements.

7. A light-emitting device according to claim 6, wherein the acceptor element is magnesium.

8. A light-emitting device substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

9. A method of producing a light-emitting device substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

The Patent Office

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Application No:	GB 9805086.7	**Examiner:**	SJ Morgan
Claims searched:	1-9	**Date of search:**	29 May 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H1K(KEAA,KELQ)

Int Cl (Ed.6): H01L 33/00; H01S 3/19

Other: Online:WPI, JAPIO, CLAIMS INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
P,X	EP 0 772 249 A2 (NICHIA) See line 24, column 16 - line 32, column 17 & lines 21-50, column 19	1-7
P,X,&	US 5 652 438 (TOYODA) See lines 43-60, column 2 & lines 21-65, column 5.	1-7
X,&	JP 8 032 112 A (TOYODA) See equivalent patent document US 5,652,438.	1-7
X	Inspec abstract number A9716-4255P-014 & Materials Science & Engineering B, vol. B43, no. 1-3, p. 265-8, M Asif Khan et. al.	1-3 & 5-7

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.